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special report

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OPTIMUM SIZE SPRAY DROPLETS

APRIL 1979

Forest Service
U.S. Department of Agriculture
Equipment Development Center
Fort Missoula
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SPECIAL REPORT

DELIVERABLE DOSE INDEX: AN APPROXIMATE METHOD FOR COMPARING EFFECTIVENESS OF PESTICIDE DROPLET SIZES

ED&T 2664

Optimum Size Spray Droplets

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ABSTRACT

A method for comparing the effectiveness of various combinations of droplet sizes, insecticides, wind speed, and other factors is presented. This is an approximate method and is based on summing droplet numbers to give a Deliverable Dose Index (DDI), which is similar to the droplets per square centimeter of ground deposit.

A report on Equipment Development and Test Project 2664--Optimum Size Spray Droplets, funded by the Forest Insect and Disease Management Staff.

CONTENTS

INTRODUCTION

The goal of the optimum size spray droplet project is to increase the efficiency and effectiveness of controlling forest insects with aerial sprays. To accomplish this, the Missoula Equipment Development Center (MEDC) is working to determine the optimum spray droplet size for varying situations, so that this data can be incorporated into requirements for application equipment. One phase of this work concerns developing a numerical method for comparing the effectiveness of several combinations of spray variables for aerial application of pesticides without extensive field testing. Such a numerical method would be useful for selecting an optimum range of droplet sizes.

Selection of an optimum range of spray droplet sizes for aerial application of pesticides to forest canopies is governed by many variables and constraints. Some can be controlled and some cannot. Some of the more important variables are:

- Active ingredient (AI).
- Dilution by carrier.
- Adjuvants.
- Median droplet size (Volume Median Diameter, VMD).
- Range of droplet size.
- Rate of application (gal/acre, AI).
- Meteorological conditions.
- Stage of larvae development.

Most of these variables are not independent in their action, and because forest conditions cannot be duplicated in a laboratory, the actual evaluation of the effectiveness, or importance, of each variable is usually performed in the field. Because of the large number of variables involved, a comprehensive field evaluation is very expensive. For example, a modest set of experiments would require each of the eight variables to assume at least two distinct values. Repeated three times, the experiments would require 778 separate forest test plots. Likewise, a rigorous analytic treatment of the problem based on the necessary principles from physics, aerodynamics, meteorology, chemistry, and biology appears to be an overwhelming task.

As a result of these complexities, an approxiate method is being proposed for comparing the effectiveness of pesticide droplet sizes based on simplifying assumptions and existing test data. The method consists of deriving an expression for the number of lethal doses that can be delivered to the foliage or insect. By implementing the calculations which follow on a digital computer the effect of different sets of parameter values on the number of lethal doses that are potentially deliverable may be readily analyzed.

Because the method is approximate, it will require further testing to assess its range of validity. However, even in its present form the method can be used to significantly increase the effectiveness of pesticides applied with commercially available spray equipment without incurring the high costs implicit in other approaches.

COMPUTING DELIVERABLE DOSE INDEX

The Deliverable Dose Index (DDI) is defined as the total number of droplets of specified spray base intensity available to impact a given target, resulting in insect mortality. The DDI is an index for comparison similar to the Dow Jones Index used in the stock market. This section describes the method of calculating the DDI.

If spray liquid is applied in uniform droplets to a horizontal surface, the number of droplets/centimeter^2, n, is given by:

$$n = \frac{17.86\ Q}{d^3}\ 10^7$$

Q = Application rate in gallons/acre

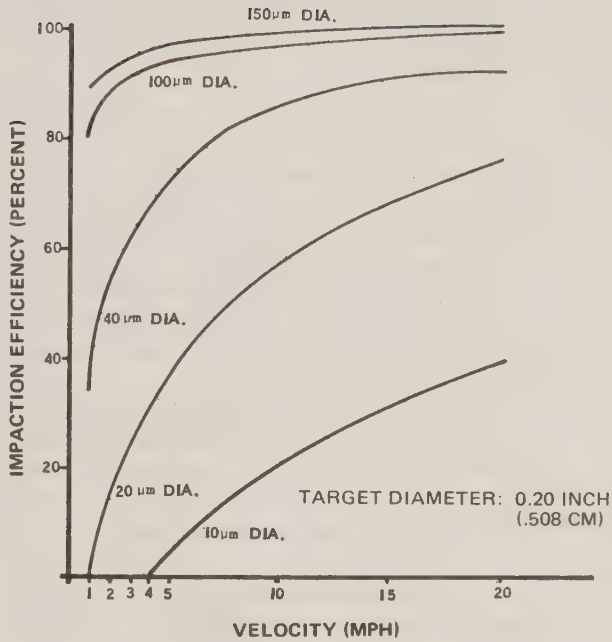
d = Droplet diameter in micrometers (μm)

Most sprays contain a range of droplet sizes. For convenience the droplets can be grouped into several classes. Then the total number of drops (TA) for a given rate of application (such as gallons/acre) can be expressed as:

$$TA = \sum n_x \qquad [1]$$

where n_x is the number of droplets in each size class projected onto a unit area.

Droplets less than 100 μm have insignificant settling velocities (< 0.5 mph) (.804 kph), and, therefore, are assumed to be controlled by air movements. An airborne droplet approaching a cylinder (conifer needle) tends to impact on the cylinder by virtue of inertia. However, the droplet also tends to be deflected away from the cylinder by the viscous forces around the cylinder. A combination of these effects results in only a fraction of the droplets impacting the cylinder. The ratio of droplets impacting the cylinder to the total number approaching the projected frontal area of the cylinder is defined as the impaction efficiency (E). Figure 1 shows the relationship between velocity, drop diameter, target diameter, and impaction efficiency. The results are taken from Brun (1955).



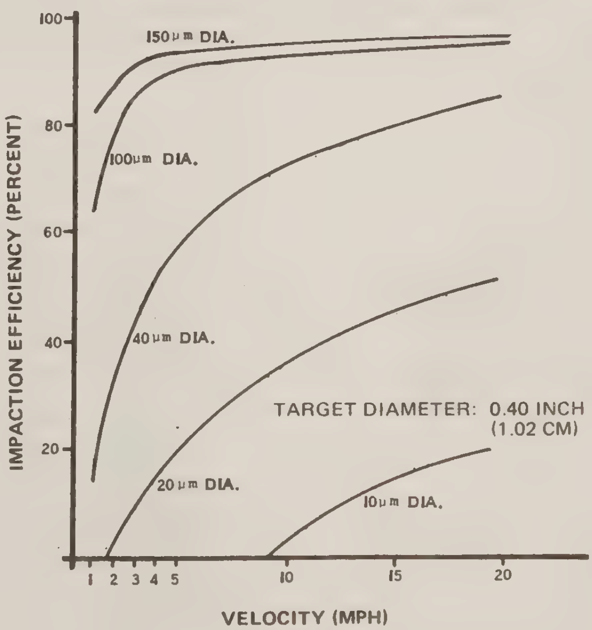


Figure 1.--Impaction efficiency of drops on a cylindrical rod.

Because some of the droplets are too small to impact on the needles, the number of droplets available at the target is reduced. By multiplying each n_x by the impaction efficiency, E_x, for the average droplet in each class and then summing the products, an expression for the number of droplets, T, is obtained,

$$T = \sum n_x E_x \qquad [2]$$

The toxicity of an insecticide is described as a lethal dose, denoted by LD_x, where x is the percent of a population killed as determined in the laboratory. For example, LD_{90} denotes 90 percent killed. The toxicity is usually given in μg (micrograms) of insecticide per gram of body weight, or ounces per acre. If the toxocity, dilution rate, size, or weight, of the insect is known, a droplet diameter can be calculated that will contain the desired LD_x. The relevant equations for determining LD_x, and further explanation are given in the appendix.

If the spray contains a large number of small droplets with sublethal doses, there is a possibility that enough small droplets will reach a single target to produce mortality. A more realistic DDI can be computed by dividing the number of droplets in each class, n_i, by the number of droplets in each class required for a lethal dose, $(n_{i_{LD_x}})$ (Equation [2]).

$$DDI = \sum_i \frac{n_i}{n_{i_{LD_x}}} E \qquad [3]$$

If the units of the variables appearing in the equation are properly selected the DDI will correspond directly to droplets/cm^2, a form commonly used in reporting spray deposition on samplers such as Kromekote cards. The DDI can be interpreted as effective droplets/cm^2.

Two examples are given showing how the DDI calculation can be used. The first example uses a droplet distribution measured during a pilot project. The second example is an estimate of improvement of DDI if a new nozzle were developed.

Example 1

The sample calculations in the example are based on field data collected during the Northern Region Pilot Project (Dewey 1975). The mass and number distribution of droplets measured during field spraying are shown in figures 2 and 3. The effective diameter of the target is assumed to be 0.20 inches (0.508 cm). The minimum lethal droplet diameter size (LD_{90} for fifth enstar spruce budworm) is given as 400 μm, based on laboratory determinations. Results based on minimum lethal droplet sizes of 40, 80, 100, and 250 μm diameter respectively, are given in figures 4 and 5 to show the effect of varying the toxicity.

The DDI for the total drop spectrum at air velocities of 1 and 6 mph respectively (1.61 and 9.66 kph) is also shown in figures 4 and 5.

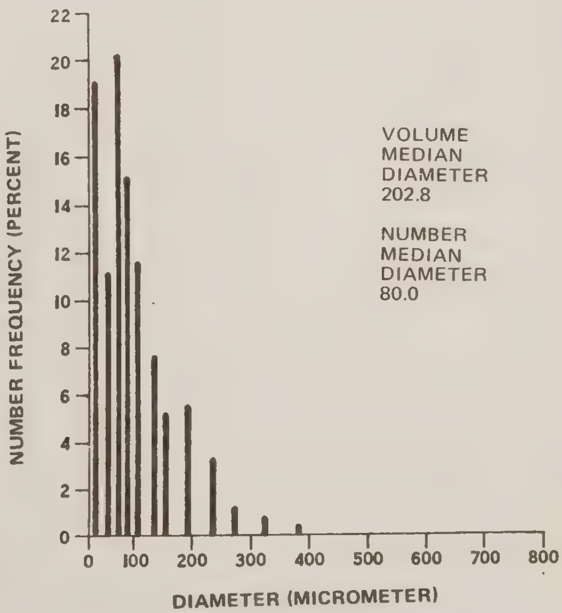


Figure 2.-- Numerical frequency distribution.

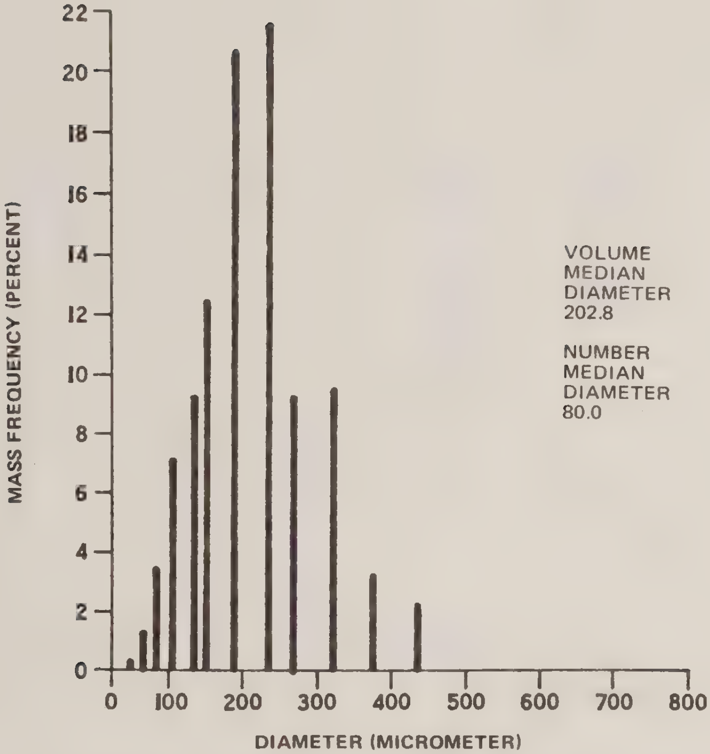


Figure 3.--Mass frequency distribution.

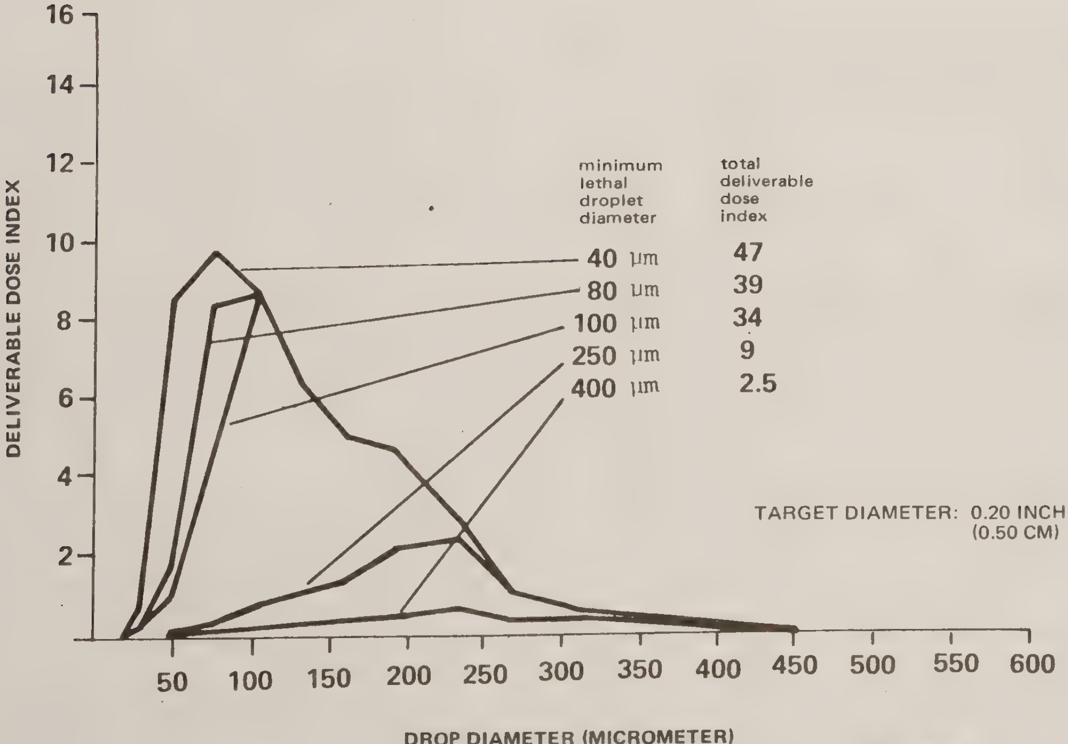


Figure 4.--Deliverable dose for 1 gallon per acre for ~~various~~ five levels of toxicity (1 mph)(1.61 kph).

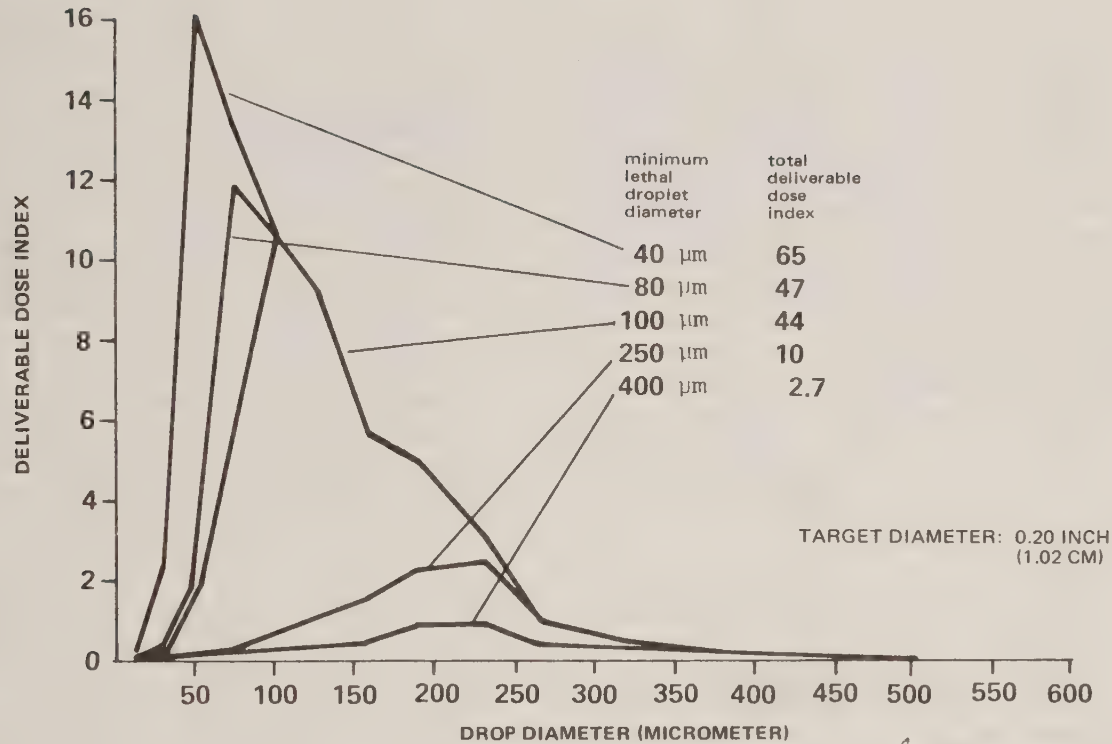


Figure 5.--Deliverable dose for 1 gallon per acre for ~~various~~ five levels of toxicity (6 mph)(9.66 kph).

Example 2

The previous example is for applications using currently available commercial spray equipment. The DDI concept is also useful to strategies involving equipment not yet designed.

For example, if a spray nozzle were developed that produced droplets equal or nearly equal in size (monodisperse), how large an improvement in droplets delivered to the target could be expected?

The DDI's for a target diameter 0.20 inches (0.508 cm), and minimum lethal droplet sizes of 80, 100, 150, 250 µm diameter and for monodisperse spray of 80, 100, 150, and 250 µm diameter respectively can be computed (table 1). In these calculations it is assumed that the spray consists of droplets of the same size and each droplet contains one lethal dose.

Table 1.--*Deliverable dose for monodisperse sprays with each droplet containing one lethal dose at 1 gallon per acre*

Droplet Diameter	DDI	
	1 mph	6 mph
µm	(1.61 kph)	(9.66 kph)
80	233	328
100	143	170
150	47	51
250	11	11

DISCUSSION

A computer program has been developed to perform the calculations necessary to determine DDI. The derivations of the equations and program listing are contained in the report "Optimum Spray Calculations" (Banaugh 1976). The program is written in the BASIC programing language and is suitable for remote terminal use in the time share mode. Several important variables, which will be discussed later, have not been included in the present calculations. However, the current program has been written to permit easy incorporation of other variables.

In the present form the following variables are considered:

- Droplet size range and distribution.
- Wind speed (at target).
- Size of larva.
- Toxicity of insecticide.
- Amount of carrier dilution.
- Impaction efficiency of droplets.

These variables were selected for the initial program because applicable numerical data were available in a readily usable form.

Other important variables that can be incorporated into the program are:

- Evaporation.
- Off-target drift.
- Canopy filtration.
- Aircraft induced velocities.

The numerical procedures for considering the effects of evaporation are more difficult because droplet diameter is constantly changing with respect to time. Reduction of droplet diameter increases drift, decreases impaction efficiency, and may concentrate the active ingredient contained in each droplet. Numerical solutions for drift have been provided by Cramer (1972). Results could be incorporated in the calculations by the simple expedient of discounting droplets that travel farther than some arbitrary distance, perhaps 1,500 feet (457 m). The justification for such an assumption is that the droplets are beyond effective control of the operator. Droplets that travel great distances contain only a small part of the total mass, even though they may be abundant numerically.

Data are available from wind tunnel tests on the effect of canopy filtration (Wedding 1978). The tests were conducted using a single tree size. Further testing, or extrapolation of present results, would be necessary to incorporate canopy filtration into the present model.

Standard texts in subsonic aerodynamics present the theory and methods for determining the velocity of an aircraft wake. In addition, recent aircraft safety considerations have led to extensive research on strength and persistence of aircraft wakes and vortices.

Little is known about the wake and vortex action at the interface of the atmosphere and canopy top. Current, as well as new information on the effect of aircraft wake could be incorporated into the computer model.

CONCLUSION

A simplified method to compare spray strategies has been developed, and programed for computer use.

RECOMMENDATION

The DDI concept and computer program should be expanded to incorporate other variables, such as:

- Evaporation.
- Off-target drift.
- Canopy filtration.
- Aircraft induced velocities.

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DETERMINATION OF LETHAL DOSES
By Robert Banaugh

There are two common experimental techniques for the determination of lethal doses. The first technique, called the topical application method, consists of individual carefully measured applications of the insecticide, followed by a determination of the percent kill resulting from the application. This technique gives the dose necessary to kill a specified percentage of larvae. The specified percentage of killed larvae is denoted by LD_x, and the required dose is expressed in units of micrograms of pure insecticide per gram of body weight of the insect.

The other technique, called the spray application method, consists of depositing the insecticide on the insect larvae with the aid of a sprayer. The drop and density distribution of the spray is accurately controlled, and the subsequent insect mortality determined. The required dose corresponding to a given LD_x is expressed in terms of ounces of pure insecticide per acre corresponding to an applied volume of spray that is specified in gallons per acre.

For both of these empirically determined dose statistics it is possible to derive a minimum droplet diameter for a specified spray concentration corresponding to a desired LD_x.

The minimum LD_x drop diameter depends on the mass of the insecticide in the drop, the body weight of the insect, the concentration of the insecticide in the spray, and the density of the pure insecticide.

The units expressing the insecticide dose, D, requiired to obtain a specified LD_x are given as μgm/gm body weight or as oz/acre (gm/m^2). Because of the two different units of measurement, the calculation of the minimum drop diameter, d, necessary to produce a given LD_x is different. The first part of this section presents the derivation of an expression for d assuming that D is expressed in μgm/gm body weight. d will be determined in micrometers.

Let: d = minimum drop diameter in micrometers,
D = required dose in μgm/gm body weight,
W = insect body weight in mg,
C = percent concentration of pure insecticide by volume of spray,
and ρ = density of pure insecticide in gm/cm^3.

The calculation of the desired drop diameter requires a determination of the mass, M, of pure insecticide that must be contained in the droplet to produce a lethal dose. Equating this expression to the mass of insecticide actually contained in a single drop gives an equation for the determination of the drop diameter.

[illegible]

[illegible]

[illegible] the drop [illegible] This [illegible] of individual [illegible] by [illegible] This [illegible]

Other variables [illegible] dry [illegible] and [illegible] is expressed [illegible] concentration [illegible]

[illegible] depth [illegible] empirically determined [illegible] and [illegible] diameter [illegible] equation [illegible]

[illegible] number [illegible] diameter [illegible] in the [illegible] the [illegible] of the [illegible] and the [illegible]

Using [illegible] the [illegible] drop [illegible] required [illegible] ounces [illegible] body weight [illegible] [illegible] the calculation of [illegible] necessary [illegible] presents the derivation of an expression [illegible] per [illegible] body weight. [illegible] will be determined [illegible]

Let: S = minimum drop [illegible] in microns,
D = required dosage in [illegible] body weight,
[illegible] body weight in [illegible],
[illegible] pure insecticide, [illegible] volume [illegible]
and Q = [illegible] of [illegible] size in [illegible].

[illegible] desired drop diameter [illegible] [illegible] [illegible] the example [illegible] an expression for the determination [illegible]

The desired dose per insect is

$$DW \times 10^{-3} \ \mu gm \quad \text{or} \quad DW \times 10^{-9} \ gm$$

of pure insecticide. The mass of pure insecticide contained in a spray droplet is

$$\frac{\pi}{6} d^3 \left(\frac{C}{100}\right) \rho \times 10^{-12}$$

where d is in micrometers.

Thus, by equating these two expressions

$$\frac{\pi}{6} d^3 \left(\frac{C}{100}\right) \rho \times 10^{-12} = DW \times 10^{-9}$$

or

$$d^3 = \frac{6 \ DW \times 10^5}{\pi \ C\rho}$$

Hence,

$$d = 57.5884 \sqrt[3]{\frac{DW}{C\rho}}$$

If the dose is given in oz/acre (gm/m^2), the determination of the mass, M, of pure insecticide that must be contained in a single droplet to produce lethal effects is accomplished by assuming that the spray is spread evenly over the area, covering the insects. It is further assumed that the shape of the insect can be approximated by a right circular cylinder whose length is ℓ_1 cm and whose diameter is ℓ_2 mm. Thus, the area, A, exposed by the insect to the spray is $\ell_1 \ell_2 \times 10^{-1}$ cm^2. If D is the dose, M is given as

$$M = 7.0053 \times 10^{-8} \cdot \ell_1 \ell_2 \ D \ gm.$$

Equating this expression to the mass of insecticide contained in a droplet gives

$$7.0053 \times 10^{-8} \ \ell_1 \ell_2 D = \frac{\pi}{6} d^3 \left(\frac{C}{100}\right) \rho \times 10^{-12}$$

or

$$d^3 = \frac{42.932 \times 10^6 \ \ell_1 \ell_2 D}{\pi \ C\rho}$$

Hence,

$$d = 237.4 \sqrt[3]{\frac{\ell_1 \ell_2 D}{C}}$$